1. Compliant packaging
   At the Hamamatsu meeting, there was consensus that the module will require a mechanically compliant element to avoid stressing the ball bonds. The “gap pad” thermally conductive material can fulfill that role. Hamamatsu approved of its use.

2. Gap pad placement.
   Optimal placement of “gap pad” is between TE and APD, or “below” TE cooler rather than “above” it. In this configuration, the gap pad need only transmit the power leaked into the APD, but not the power dissipated in the TE cooler. This should limit the temperature drop on the gap pad to only a few deg-C.

3. APD Module connections.
   The APD Module must be connected on one side, to the fiber manifold / cookie, and on the other side to the Front End Electronic box. **There must be compliance in this connection so as to avoid stressing the APD/cookie interface.** This can, in principle, be done in one of two ways;

   - Flexible connection between cookie and manifold.

   OR

   - Flexible connection between APD module and Front End Box.

   We believe the first option is far more difficult and painful than the second. Therefore →
   - A short (1-2 cm) flex-cable interface between the APD Module and the Front End Box is the preferred solution.
   - This interface must be “pluggable” to allow for easy APD Module replacement.

4. Hamamatsu deliverables
   The original Hamamatsu plan included the TE cooler. The presence of the gap pad under the TE cooler now decouples it from the APD deliverable. Hamamatsu will now deliver;
   a. APD bump bonded to substrate provided by NOvA.
   b. Epoxy under-fill → ***No discussion as to whether this is vacuum tight***
   c. Ceramic backer plate (380u) epoxied to APD
   d. Thermistor epoxied to ceramic plate.

5. TE cooler reliability.
   Industry standard figure for MTBF is 200,000 hrs or 23 years. Various vendor information claims MTBF dependence on
   - Temperature
   - Thermal shock
   - Mechanical stress
   - Corrosion

The available information is, however, not very quantitative. It would seem that the vendors foresee failures due to “lack of proper treatment” of the devices and don’t want to be responsible. Therefore, it’s up to us to get it right.

6. Failure rate and packaging considerations

NOvA will deploy 25,000 TE coolers, which, using the industry standard MTBF of 23 years, leading to a failure rate of ~1,100/yr or ~3/day. It’s up to us to mitigate this figure to get the lowest possible failure rate.

- Low stress packaging
- Low temperature operation → liquid cooling
- Low thermal shock → controlled cool-down cycle
- Corrosion mitigation → inert gas enclosure
- Vacuum tightness of epoxy under-fill is not guaranteed. → Inert gas flush, but probably no vacuum purge unless this can be guaranteed by vendor.

7. Cooler replaceability

Assuming we do the most careful module design possible, mitigating all known failure modes, we might still wind up with a failure rate of anything from ~3/day to, perhaps optimistically, ~1/day or less. We will not know this unless we do a long term controlled test procedure on perhaps 1,000 modules. Thus, we have the requirement that ***TE coolers must be replaceable***. In fact, they should be ***easily replaceable.***

If no magic bullet to improve TE cooler MTBF can be found, NOvA may have to plan for, and live with, a daily failure/replacement rate of one or more TE coolers per day.